RESEARCH DEPARTMENT

A New Photoelectric Optical Bench

Report No. T.049

Serial No. 1954/34

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

A NEW PHOTOELECTRIC OPTICAL BENCH

Report No. T.049

Serial No. 1954/34

WProctor Wilson

W.N. Sproson, M.A.

(W. Proctor Wilson)

This Report is the property of the British Broadcasting Corporation and may not be reproduced or disclosed to a third party in any form without the written permission of the Corporation.

Report No. T.049

A NEW PHOTOELECTRIC OPTICAL BENCH

Section	Title	Page
	SUMMARY	1
1	INTRODUCTION	1
2	METHOD OF MEASUREMENT	2
	2.1. Square Wave Grating Pattern Method	3
	2.2. Slit Method or Unit Impulse Method	3
3	DESCRIPTION OF THE BENCH	4
4	TYPICAL RESULTS	9

CONFIDENTIAL

Report No. T.049

December 1954

Serial No. 1954/34

A NEW PHOTOELECTRIC OPTICAL BENCH

SUMMARY

An outline of the photoelectric method of testing lenses is given, together with some details of the two types of test pattern now in use and the form of aperture correction necessitated by the finite width of the scanning slit. The photoelectric test bench is described and a few preliminary results are quoted.

1. INTRODUCTION.

This optical bench has been designed for testing lenses intended for use with television systems. It might be considered that the standard of definition used in television is relatively low and much below the limiting resolution of most lenses, so that no consideration need be given to the lens. This in fact is a simplification of the situation, because, although the limiting resolution of most lenses is very high (in terms of television definition), lenses do suffer some loss of contrast at the pattern frequencies corresponding to television picture detail*. Further, it has been found experimentally that a change of lens can make a noticeable difference to picture definition on a television monitor.

The order of magnitude of pattern frequencies involved in television images is 10 patterns (or optical lines) per mm. In the case of an image orthicon with a photocathode diagonal of 40 mm, the pattern frequency corresponding to 3 Mc/s on BBC standards is 8 patterns per mm (ppm). 3 Mc/s bars recorded on 35 mm film correspond to 12 patterns per mm and on 16 mm film the figure rises to 26 ppm.

---

*W. N. Sproson, "The Measurement of the Performance of Lenses", BBC Quarterly Vol. 8, pp 17-26, 1953.

2. METHOD OF MEASUREMENT.

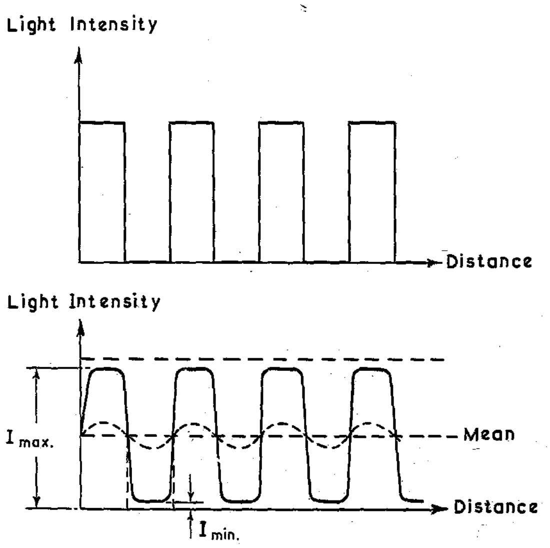


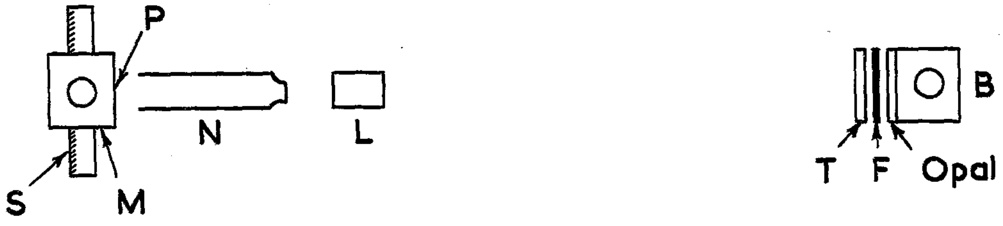
Fig. 1 - Original square wave grating pattern (above) and its reproduction by a lens (below)
Solid line represents a low pattern frequency and dotted line a much higher frequency

If we consider the reproduction of a square wave grating pattern of high contrast ratio (Fig. 1) by a lens, the image will not be a perfect copy of the original with merely a scaling factor for change of size. Some loss of contrast is encountered. At low pattern frequencies this is slight but at higher frequencies only a sinusoidal variation is found with relatively low amplitude. Modulation is here defined (for optical work) as

$$\frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

where I is the light intensity. This is identical with "visibility" as defined by Michelson and is a more useful scale to use than contrast ratio, although of course it is directly related to it.

An outline of the method is shown in Fig. 2. Light from a tungsten lamp is diffused by an opal diffuser and then passes through the test pattern. Colour filters can be interposed between the test pattern and light source if required. The lens under test images the test pattern and it is necessary to measure the variation of light intensity in the plane of focus. If it were easy to make slits of the order of 10 μ width, the image would be measured in its own plane, but for convenience the image is magnified by a suitable apochromatic microscope objective and the magnified image is scanned by a slit in a box containing a photomultiplier. In an elementary form of the apparatus this box is mounted on a travelling microscope stand and thus can be made to traverse the image.



B.	Light source
F.	Neutral and/or colour filter
T.	Test Pattern
L.	Lens under test
N.	Microscope (less eyepiece)
P.	Narrow slit
M.	Box housing photomultiplier
S.	Scale of travelling microscope stand

Fig. 2 - Method of measuring the modulation characteristics of lenses

Variations in the light flux between different parts of the image cause variations in the photocurrent, which are read off on a meter. A D.C. amplifier with negative feedback is used to avoid the need for a very sensitive current-measuring instrument. The biasing arrangement permits easy setting of the meter so that the dark current of the photocell is not recorded.

Two sorts of test pattern are used (a) a series of square wave grating patterns and (b) thin slits.

2.1. Square Wave Grating Pattern Method.

The modulation to square waves is recorded for a suitable range of pattern frequencies. The correction to be used for the finite width of slit has been evaluated on the assumption that the degradation of image quality of the square wave test pattern produced by the lens is similar to that produced by a lens limited only by diffraction. The set of curves thus obtained is shown in Fig. 3. In any practical case, the curves of Fig. 3 will be only approximately correct, but the main interest for television purposes centres around the 0 to 0·1 f/f_c region, so that the corrections are not large. Thus, errors in the correction have only a very slight effect upon the final result.

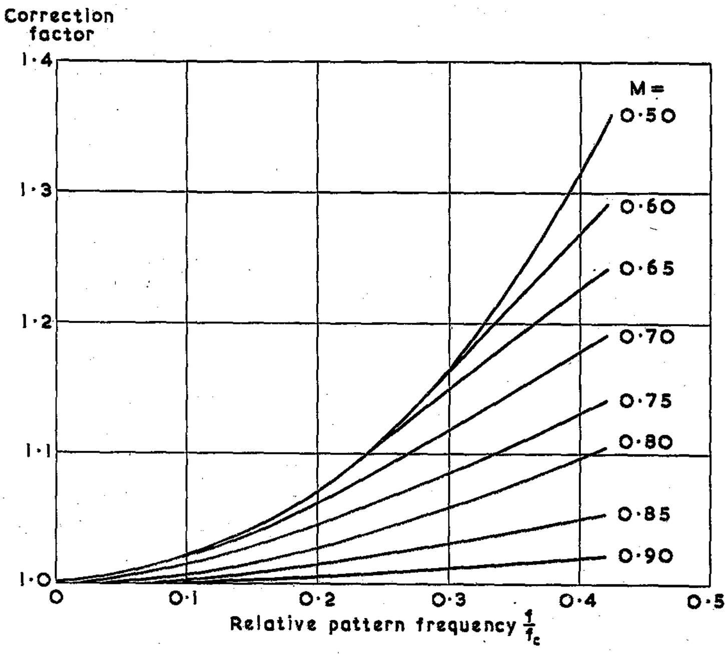


Fig. 3 - Aperture correction curves for square wave modulation

2.2. Slit Method or Unit Impulse Method.

This method is the optical analogue of impulse testing in electronic circuits. A narrow slit is used as the test pattern and a determination of the intensity versus distance relationship in the plane of focus is made. The Fourier transform of this gives the modulation/frequency response, but in this case it is the modulation to sine waves. Aperture correction is no longer subject to the uncertainties which were present in the case of square wave test pattern, and one can correct precisely for the finite width of both scanning slit and source slit. There is the further advantage that the sine wave response does give the response at one frequency only, whereas the square wave response is the sum of the responses over a range of frequencies.

Given the sine wave response of a lens, it is not difficult to calculate from the Fourier series its square wave response. Likewise the sine wave response can be deduced from the square wave response, although in this latter case the algebra is slightly more troublesome*.

3. DESCRIPTION OF THE BENCH.

The photoelectric optical bench is a modification of a Mark I Optical Test Bench designed and built by Messrs. Taylor, Taylor and Hobson. This particular design has now been superseded by the manufacturers, but it offers the basic facilities that are required for photoelectric testing. As will be seen from Fig. 4, the bench consists of a light source [A], which, with a suitable condensing system illuminates the test object. The test objects are either square wave grating patterns or relatively fine slits, corresponding to the two methods just described. Sixteen different test objects are available from one test object disk, and the different test objects can be easily changed from the observation end of the test bench. Two other disks are mounted on the same horizontal axis behind the test object disk and contain neutral density filters and colour filters respectively.

Light from the test object is collimated by a 1524 mm f/15 collimating lens [B] and passes on to the lens under test [C]. This is mounted on a shake-free ball-race of large diameter (127 mm, 5 in.) [D], which is part of a carriage [E] that runs on to a turntable [F]. Light from the lens under test forms an image which can be accurately located in a plane which includes the vertical axis of a bearing which is located on the bridge of the optical bench [G]. This bearing takes a vertical plate which holds the photographic plate holder which is used when photographic results are required: it is arranged that with a photographic plate in position the emulsion surface contains the vertical line through the centre of the bearing [H] on the bridge [G], Fig. 5. When the turntable is rotated, the lens can be adjusted to rotate about its rear nodal point and the distance from the lens to the central axis through the bearing is automatically increased by (sec θ - 1) by the action of the Tee-bar (or sine bar) [I]. Coarse and fine adjustments for both focus and turntable positions are provided (micrometers [1] and [2], Fig. 6), so that it is a relatively easy matter to set up a new lens (always provided that a suitable mounting flange is available).

So far the bench has been described substantially in the form in which it was originally made. The modifications which were carried out involved removing the original microscope from the bridge and fitting a microscope and photocell attachment which is capable of lateral and vertical movements so that the image can be scanned in two mutually perpendicular directions. A close-up of this is shown in Fig. 6. There are three metal blocks, [K], [L] and [M], of which the bottom one [K] is fixed to the bridge. The second one [L] moves upon this in a direction parallel to the axis of the bench. Kinematic design principles are used here——3 ball bearings moving upon 2 Vee's and a flat. The third block [M] moves on the second and is capable of movement perpendicular to the axis of the bench. It is driven by a micrometer [3] which is marked to 5 μ intervals and can be estimated to 1 μ by inspection. Upon the third block [M] a hollow cylinder [N] is mounted with its axis vertical. Inside this cylinder is fitted another cylinder which takes the microscope tube [O]. The inner cylinder can be driven up and down by a micrometer thread [P] and the movement can be measured by the scale markings on the upper milled head, which serves as a micrometer [4].

---

*Appendix 3, B.B.C. Research Department Report No. T.039

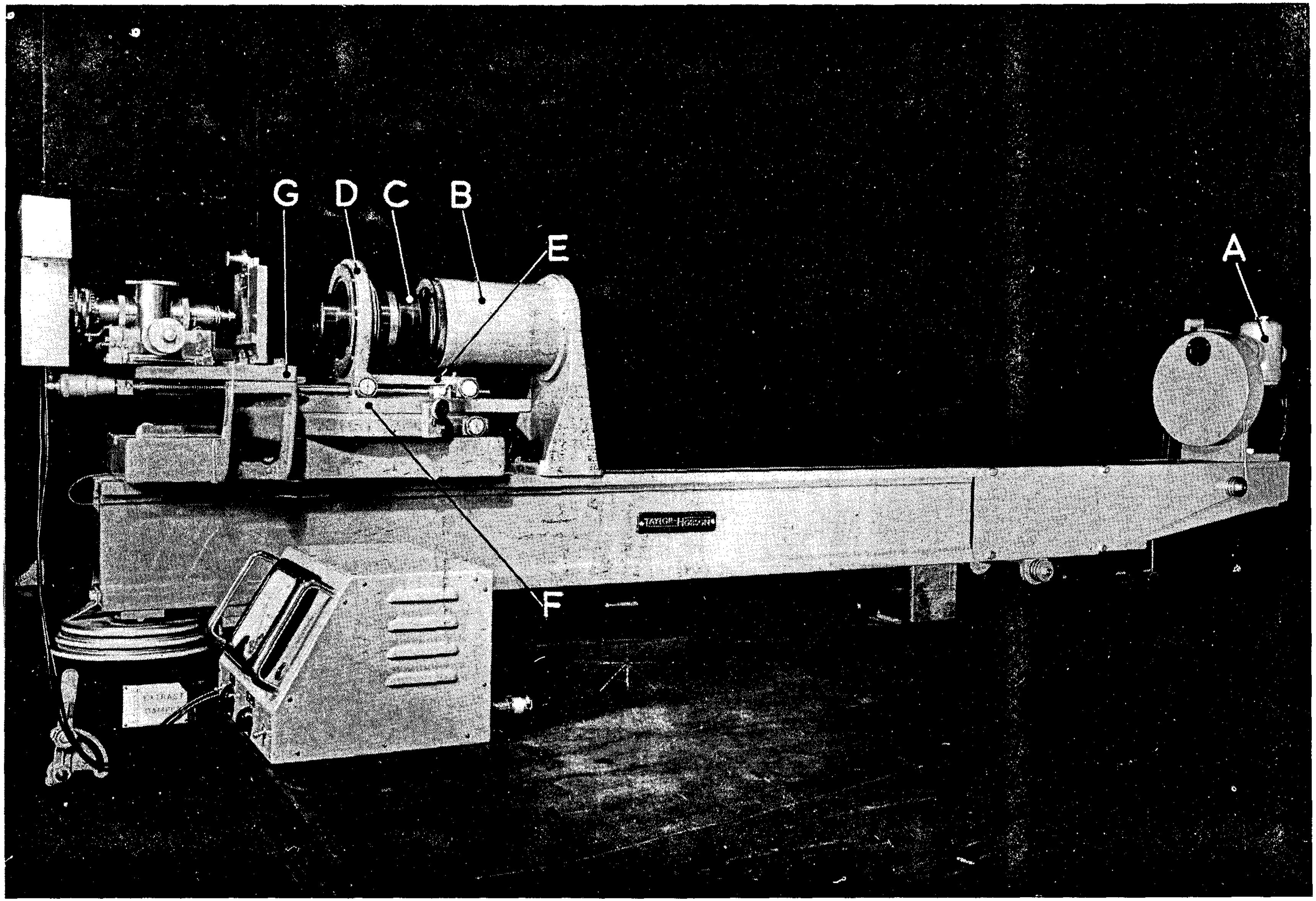


Fig. 4 - General view of the optical test bench

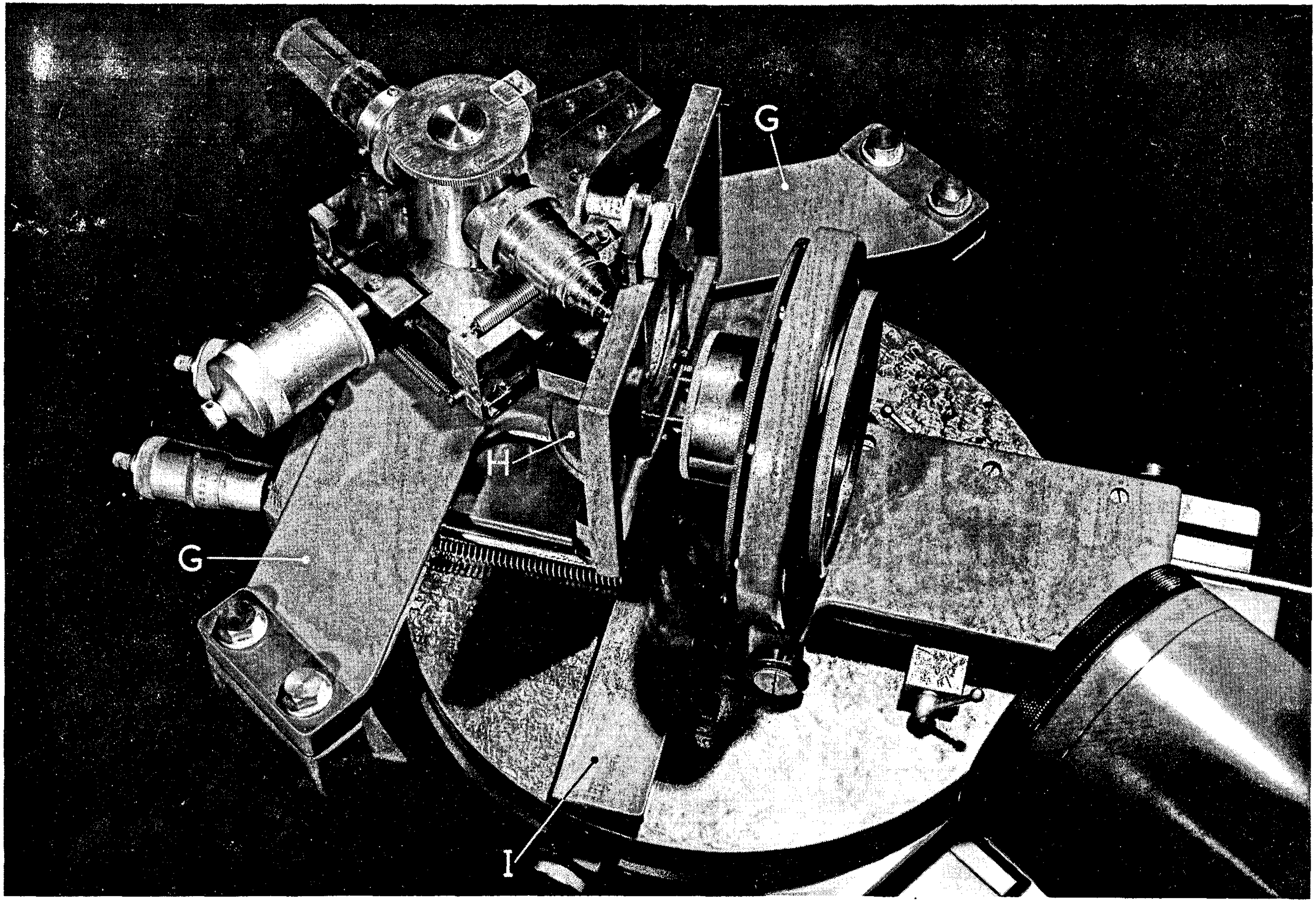


Fig. 5 - Nodal slide turntable of the optical bench
This view shows an eyepiece in place of the photocell housing:
the eyepiece is used for setting-up purposes

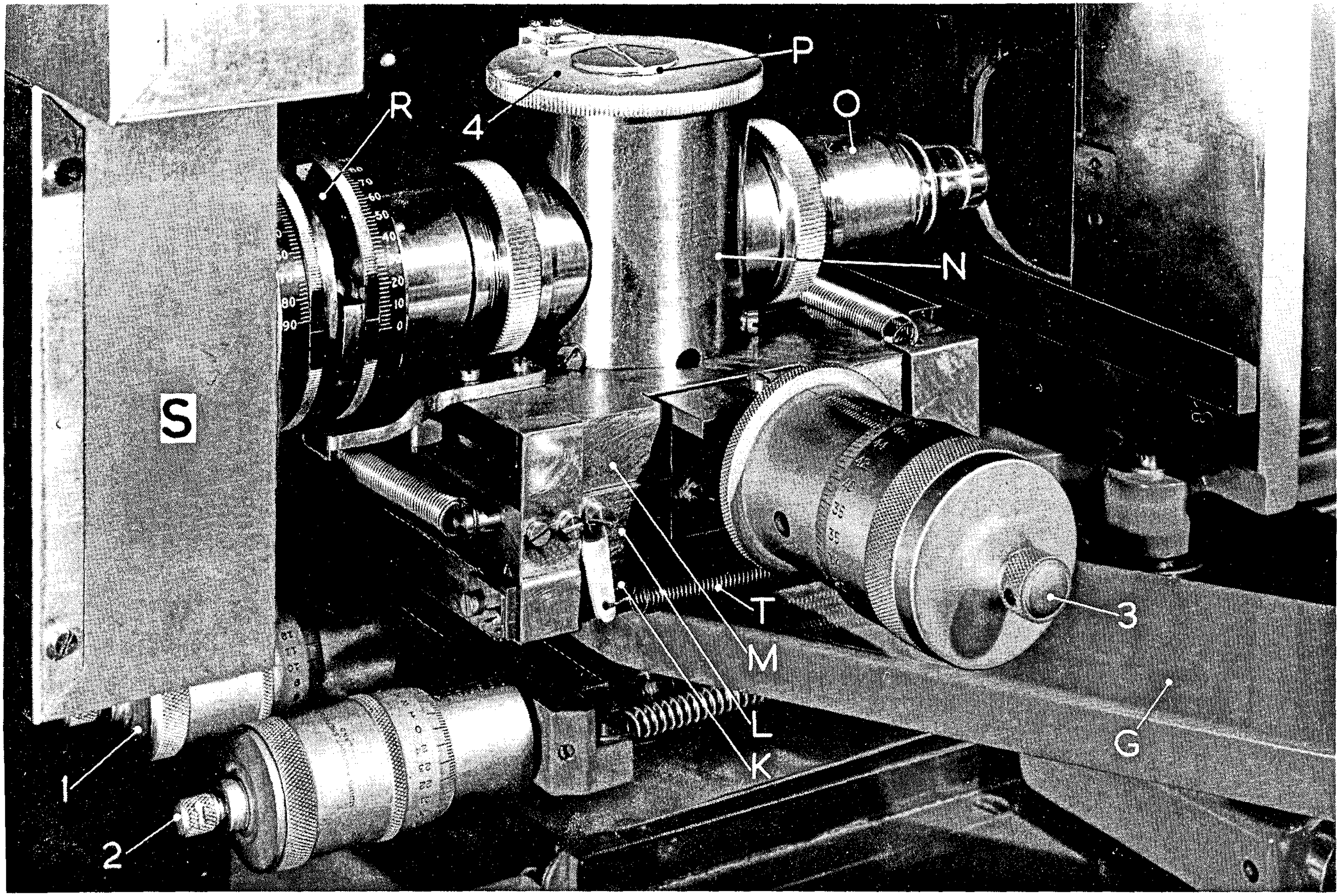


Fig. 6 - Details of the photoelectric scanning part of the optical bench

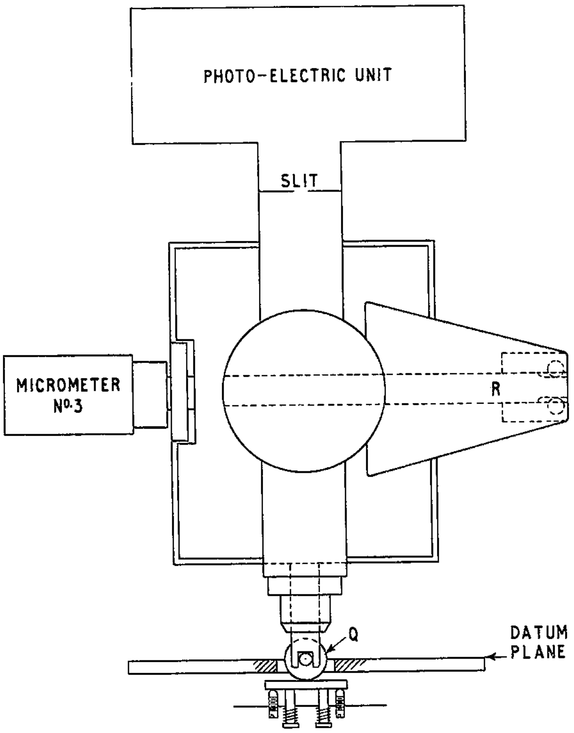


Fig. 7 - Plan of photoelectric bench to show correct position of roller bearing Q

In order to prevent rotational movements of the microscope tube, an arm ([R], Fig. 7) is taken out from the inner (microscope) cylinder and is accurately located so that whilst vertical movement is permitted, maximum possible rotation is equivalent to much less than $25\ \mu$ displacement on the part of the objective, Fig. 7.

The whole assembly is kept a fixed distance from the datum plane (i.e. proper image plane) by a roller bearing [Q], Fig. 7, which is kept in contact with a bearing plate let into the photographic vertical plate mounting by two horizontal springs, one of which is shown as [T] in Fig. 6. The bearing plate can be adjusted by three screws, two of which are shown in Fig. 7, so that

(a) it is accurately parallel to the datum plane,

(b) the centre of the roller bearing [Q] is made to coincide with the vertical axis of the bearing on the bridge.

In this way, when the nodal slide is rotated, thereby causing the lens and photographic plate holder also to rotate, the microscope will then follow the true image plane upon being given a lateral movement by micrometer [3]. It is granted that the depth of focus of the microscope objective may well not be sufficient to image the whole field, but it is only the centre of the field that is used by the thin slit passing light flux to the photocell.

The same argument does not apply to vertical scans (when the slits and test pattern bars are horizontal) and here depth of focus is required to some extent. The results obtained to date do not suggest that there is serious trouble on this account.

Light from the aerial image is magnified by a suitable microscope objective (16 mm or 8 mm apochromat) and a small part of this light flux is selected by a variable slit [R] (Fig. 6) and passes on to the multiplier photocell housed inside the box [S]. The current from the multiplier photocell is amplified by a D.C. amplifier and read off on a moving coil milliammeter.

It is proposed in the near future to convert the bench to automatic recording using a thin horizontal or vertical slit as a test object (section 2.2).

4. TYPICAL RESULTS.

A few preliminary results are included. The curves include the effect of collimator lens and microscope objective as well as the lens under test. There is some reason to believe that the effect of the collimator may not be entirely ignored and tests are being undertaken to measure this. The microscope objective, a 16 mm apochromat of N.A. 0·3, is considered to be good over the frequency range concerned. Fig. 8 shows the modulation characteristics of a 50·8 mm f/2 lens at f/2 focused at 0° for 7½ ppm. The modulation at 3 Mc/s (8 ppm) is shown in the inset diagram.

If the same lens is focused for 60 ppm the curves (Fig. 9) change in shape and the field is now much more constant right out to the periphery, but at a lower modulation level.

Fig. 10 shows the results of Fig. 8 converted to sine wave response.

Fig. 11 shows the results for another 50·8 mm f/2 lens. This one does not show any marked dependence of its characteristic on the focusing frequency. It is of interest to note that it is better than lens [A] over the BBC television band, although not so good at 30 ppm, for axial imagery and off-axis imagery up to 15°.

Fig. 12 shows the results for a 152.4 mm f/2 lens using the unit impulse method. Here the results were directly obtained as sine wave responses from the Fourier transforms of the space function.

The assessment of a set of modulation curves is not an easy matter and work is at present in progress on a suitable "index of merit", which, it is hoped, will enable the characteristics of different lenses to be integrated and compared.

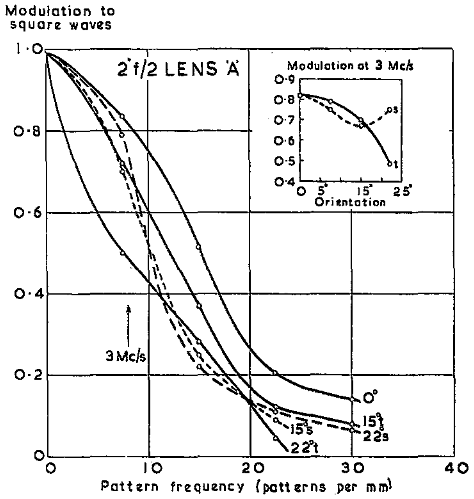


Fig. 8 - Modulation/frequency characteristics of 2" f/2 lens 'A' Focus optimum for 7½ patterns per mm

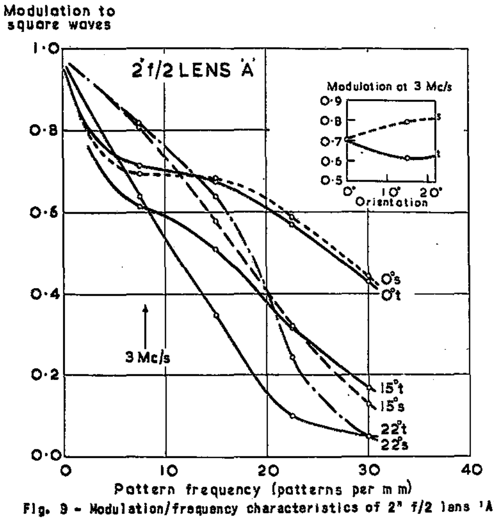


Fig. 9 - Modulation/frequency characteristics of 2" f/2 lens 'A' Focus optimum for 60 patterns per mm

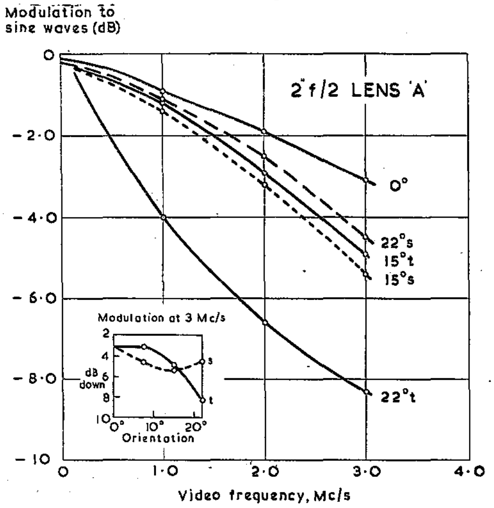


Fig. 10 - Sine wave modulation curves for lens 'A' with optimum focus at 7½ ppm

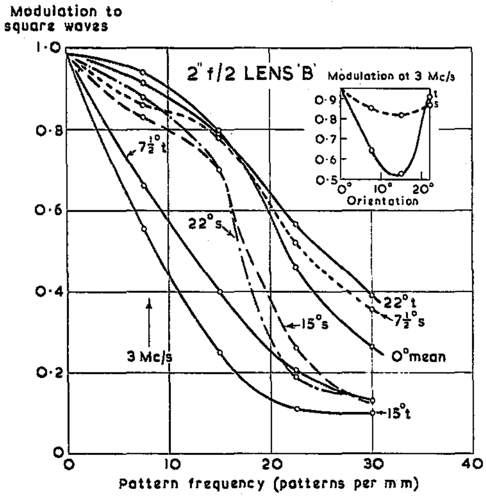


Fig. 11 - Modulation/frequency characteristics of 2" f/2 lens 'B'

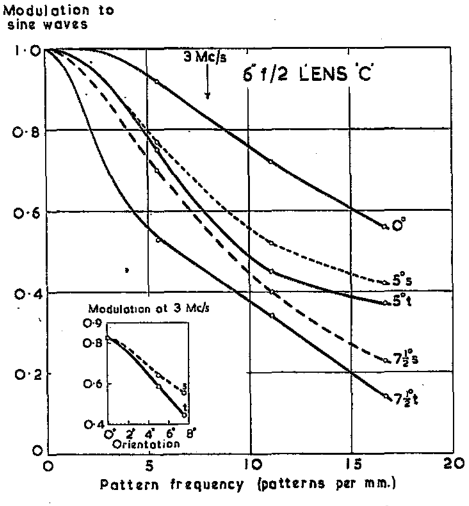


Fig. 12 - Sine wave modulation curves of 6" f/2 lens 'C'